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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improved process and apparatus for Depositing Metal Films on Substrates

We, AMERICAN COMPONENTS INC., a corporation organized under the laws of the State of Pennsylvania, United States of America, of 8th Avenue and Harry Street, Conshohocken, Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a process for producing a thin metallic film on a substrate by the technique of subjecting the substrate to the metal vapour under conditions of heat and vacuum, and to an apparatus for carrying out the process.

The technique of vaporizing metal under vacuum is well known. The technique has been employed to some extent in the production of electrically-resistive films on suitable substrates (such as substrates of ceramic material, for example) to provide electrical resistors. In the course of such a procedure, initially, a strip of a particular metal, which is to be vaporized, is wrapped around a heating element such as of tungsten wire, or a "boat" is shaped in the tungsten element and the metal to be vaporized is placed in the "boat." Thereafter the heating element is heated under a high vacuum condition and the particular metal melts is vaporized and is deposited on each exposed or outer surface of each substrate.

In order to produce a uniform film on each substrate, or resistor blank, there must ideally be some means of uniformly exposing each exposed or outer surface thereof towards the source of metal vapour. Heretofore the techniques employed in an attempt to obtain such uniform exposure involved using some version of the so-called "Ferris Wheel Method". Generally in the Ferris Wheel Method the resistor blanks are fastened by wires to the periphery of a wheel and the wheel is rotated about a heating element or a source of metal vapour.

[*Price 4s. 6d.*]

In one version of the Ferris Wheel Method the substrates are freely suspended from the wheel and are revolved thereby around the heating element. In another version the individual substrates or blanks are rotated about their own axis as well as around the axis of the wheel.

These above-mentioned techniques have one or more of the following disadvantages. First, since the substrates have to be fastened to the periphery of the wheel, they must normally be hollow tubes of ceramic material which allow a wire to be passed through the centre thereof (for fastening purposes) rather than solid ceramic rods. Tubular shaped ceramic substrates are more costly and fragile than the solid ceramic rods. Secondly, the labour for fastening and unfastening the substrates to and from the wheel is another costly factor and the operations are relatively slow. A third disadvantage is that there is little flexibility in changing the distance between the source of metal vapour and the substrates since the locations on the wheel are fixed. Fourthly, the substrates are subjected to the metal vapour during their entire 360° excursion around the source thereof and this arrangement gives rise to a shortened deposition time which, in turn, leads to control problems.

According to the invention there is provided a process for producing a thin metallic film on a substrate by the technique of subjecting the substrate to the metal vapour under conditions of heat and vacuum, in which process a plurality of said substrates are caused to be tumbled together while being subjected to the metal vapour under said conditions of heat and vacuum, and the proximity of the source of metal vapour to the overall volumetric space occupied by said plurality of substrates while they are being tumbled is variable to enable control of the process.

Apparatus according to the invention for carrying out the above process, includes an evacuable chamber, a hollow drum in said eva-

cuable chamber rotatable about a horizontal axis, said drum having means which upon rotation of the drum cause a plurality of substrates to be tumbled together when positioned therein, a heating element positioned within the chamber and means for closely associating, in operation, said heating element with a metal to be evaporated, and a device by means of which it is possible to vary the proximity of said heating element (and thereby in operation the source of metal vapour also) to a lowermost internal region of the drum occupied in operation by said plurality of substrates.

The tumbling action imparted to the substrates by the process and apparatus of the invention ensures even exposure of their exposed or outer surfaces towards the source of metal vapour. Furthermore because of the tumbling action, some substrates are buried beneath others for periods of time during the whole process. This increases the total time for which the process need be carried out to produce a desired metallic film and this leads to facilitated control as will be explained hereinafter. Also, since the substrates are not each supported but are tumbled freely, there is no danger of the metallic coating or film being impaired due to masking by a support for the substrate. Also, no time or labour is required to support the substrates on the apparatus, as is necessary with prior art devices and processes, and cheaper solid form substrates can be used. It should also be realized that, since the total length of time during the process that a substrate is buried beneath other substrates depends largely upon the rate of the tumbling action and this in turn is dependent upon the speed of rotation of the drum another control factor is introduced. This control factor is not possible in the above-mentioned prior art methods where each substrate is continuously exposed to the metal vapour. Furthermore, since the process and apparatus of the invention permits the proximity of the source of vapour to the substrates to be varied, this provides an added advantage in controlling the quality of the thin metallic film dposited on the substrates. This feature also provides another factor enabling the rate of deposition to be controlled.

According to another desirable feature of the process and apparatus according to the invention, the substrates are generally shielded from the source of metal vapour by means of a shield placed between the source and the substrates, the shield having an aperture of variable size which provides a special access area via which the metal vapour can reach the substrates. As will be explained more fully hereinafter this feature provides an important control advantage, especially when it is desired to deposit very thin metallic films on the substrates.

The process according to the invention and one form of apparatus for carrying it into practice, and a modification of the apparatus, are hereinafter particularly described by way of example, reference being made to the accompanying drawings, in which:—

Figure 1, is a somewhat, diagrammatic, perspective view of one form of apparatus for carrying out the invention,

Figure 2, is a perspective view of a boat-shaped heating element, and

Figure 3 is a somewhat diagrammatic sectional view of a modification of the apparatus of Figure 1.

Referring to Figure 1, apparatus of the invention is shown comprising a double platform having surfaces 11 and 13. A rotatable hollow drum 15 is supported by four friction drive rollers 17, two of which can be seen to the right of Figure 1. Two other identical friction drive rollers (only one of which is partly visible) support the drum 15 on its other side. Although the rotatable drum 15 is depicted as being friction driven by the rollers 17, it should be readily understood that other ways of driving the drum 15 could be employed.

The friction drive rollers 17 are fixedly secured to a pair of spaced-apart axes 19 journalled in support brackets 21. The brackets 21 are secured to the surface 11. Fixedly secured to one end of each axle 19 is a pulley 23. Looping the pulleys 23 and a drive pulley 25, is a belt 29. Although a belt drive is shown in Figure 1, obviously a chain drive or chain-of-gears drive could be used.

As a motor 31 drives a shaft 27, a bevel gear 28 engaged on the shaft meshes with and drives a bevel gear 30. Gear 30 is fixed to a shaft 32 on which is also fixed the drive pulley 25, the shaft being journalled in a support bracket 34. The shaft 27 passes through the surface 11 by means of a vacuum sealed sleeve 36. As the pulley 25 rotates, the pulleys 23 also rotate and the drum 15 is rotated by the friction rollers 17. The motor 31 is a variable speed motor, so that the speed of rotation of the drum 15, and the rate of tumbling of substrates placed in the drum, can be controlled as required.

Although it was mentioned earlier that other types of drive systems can be used, the simple friction drive depicted in Figure 1 does provide advantages for unloading substrates from the drum 15 and cleaning the drum. Since the drum 15 nests on the rollers 17 it can be easily removed by lifting, and held on end to enable substrates to be dumped out. Other types of drive would entail disengaging some mechanism.

It should be noted that flanges 33 provided on the ends of the drum limit movement of the drum in a direction parallel to its axis of rotation. As the drum 15 moves axially the flange 33 abut the rollers 17 and limit such axial movement.

Through the end opening 35 of the drum 15 there can be seen depicted two fins 37

and 39. Actually similar fins are spaced apart around the entire inside surface of the drum 15. The fin 37 is disposed at an angle such that a plurality of substrates, two of which are depicted at 41, is tumbled toward the front (with respect to Figure 1) of the drum 15 at the drum is rotating clockwise. The fin 39 disposed at an angle such that a plurality of substrates are tumbled toward the rear of the drum 15 as it rotates clockwise. The remaining fins (not shown) are similarly alternately oppositely angularly disposed. By virtue of this tumbling effect the surface or surfaces of each of the substrates is fully exposed to the source of metal vapour. Fins or agitating members of other shapes can readily be employed.

Actually the substrates are contained in operation in a lowermost internal region of the drum 15 in the form of a pile thereof. The tumbling effect just described causes substrates on top of the pile to work to the bottom of the pile and substrates on the bottom to work their way to the top of the pile. This tumbling, churning or cyclical movement of the substrates within the pile ensures that each gets its fair share of metal vapour evenly deposited thereon. In addition the substrates in the pile tend to shield one another in turn and this extends the time of the coating process, which provides better end products, as will be more fully discussed below.

As shown in Figure 1, a heating element 43 is supported by a variable positioning device 45. A wing nut 47 is unscrewed to allow an upper portion 49 of the positioning device 45 to be moved up and down. When the correct position for the heating element 43 within the drum is attained, the wing nut 47 is tightened thereby holding the upper portion 49 in place. The element 43 can be varied in position over a distance substantially equal to the diameter of the opening 35.

In order to mount the element 43 in place, a wing nut 51 is unscrewed or loosened. The halves of the upper portion 49 (which are permanently bonded together along their lower portion) are spread and the heating element 43 is inserted therein. Subsequently the wing nut 51 is tightened to hold the heating element 43 secure. On the visible end of the heating element 43 there is an insulation sleeve 53 which electrically isolates the heating element from the device 45.

In a preferred embodiment the heating element 43 is elongate and extends within the drum parallel with the axis of rotation thereof and a second positioning device (not shown) is located at the other end of the drum 15 adjacent to the opening at that end. The second positioning device is identical to the positioning device 45 just described. While a second positioning device is employed in a preferred embodiment, it has been found that the mechanism will successfully operate with only one positioning device.

Wires 59 and 61 connect a power supply 57 to a pair of lugs 55 (only one of which is visible) secured one to each end of the heating element, the wires passing through vacuum seals in the surface 11.

A strip of a metal to be vaporized can be wound around the heating element 43, or the heating element 43 can be formed into a "boat" to hold the metal to be vaporized. Figure 2 shows a boat-shaped heating element 43a. The metal to be vaporized is inserted in the hollow 63 of the boat-shaped element. The heated element is heated with the hollow 63 facing upward until the metal melts and flows over the sides of the "Boat." The melted metal adheres to the element 43a and then the element can be repositioned with the hollow 63 facing downward toward the bottom of the drum 15 wherein the substrates are located. The element 43a is reheated to high temperature to drive the metal off in vapor foam. Either the use of the boat-shaped element 43a, or wrapping a strip of metal around the heating element 43 (Figure 1) is satisfactory.

In Figure 1 there is shown in chain-dotted outline a bell jar 65 which, together with surface 11, forms an evacuable chamber. After a plurality of substrates to be metal coated have been loaded into the drum 15 and the heating element 43 has been properly positioned therein, the bell jar 65 is placed on the surface 11 as shown. A vacuum pump 67 is connected through the surface 11 to evacuate the bell jar 65 by means of a hose 69. When the bell jar 65 has been evacuated by the pump 67 the metal coating process can take place.

The speed of rotation of the drum 15 must be varied to accommodate the size and number of the substrates if mixing is to be optimum. For instance, the larger the substrate the faster the drum 15 must be rotated.

As described, the location of the heating element 43 can be varied within the drum 15. The variable positioning of the heating element 43 is very important to effect a control for the metal deposition process, since the intensity of deposition varies inversely as the square of the distance between the source of metal vapour and the substrates. It has been found that, when depositing metal on the substrates to form resistors, if the metal deposition process is of relatively low intensity, the uniformity of the deposited thin metallic film is excellent and hence the characteristics of the resistors are very satisfactory. It has been found that there is a correlation between low intensity deposition of the metal and long stability of the resistors. However, the deposition process cannot be unduly prolonged because it also has been found that prolonged heat

leads to unnecessary control problems. By being able to adjust the location of element 43, the proper deposition intensity can be attained.

Since the intensity of deposition can be held on the low side of the continuum the so-called "deposition inertia" is not as detrimental when employing the present system as it is in other systems. That is, after the heat has been switched off very little metal vapour deposits on the substrates.

When a resistor having a high ohmic value is to be produced, the conductive film must be made very thin. However, since there is a practical limit of thickness below which a thin film cannot be effectively mass produced and still provide uniform resistance characteristics, such high ohmic valued resistors are often produced by helically cutting or grooving the thin conductive film. A helical cut provides a current path which is physically longer and narrower than the full circumferential surface of the substrate. When the thin conductive film is helically cut, it is necessary that a thin film be uniformly distributed over the substrate, so that the resistance doesn't vary from one part of the spiral path to the next. The requirement of uniformity for a helically cut resistor is more critical than for a full substrate surface resistor because in the latter there is room for balancing out the non-uniformity since the whole surface is used.

In order to produce an extremely thin conductive film with good uniformity, a shield 75 as shown in Figure 3 is employed. Within the shield 75 of Figure 3 there is provided an aperture 77. The size of the aperture 77 can be varied by adjusting the two sides of the shield 75. As the metal vapour travels from the boat 63a, it can only effect the substrates 79 by passing through the aperture 77.

It is to be understood that the mechanism of Figure 3 is included with and in addition to the mechanism shown in Figure 1. For simplicity of explanation, the components of the device in Figure 1 are not shown, but in actual practice the entire device of Figure 1 is used with the shield 75 of Figure 3.

The shield 75 can be made of material which has a minimum of out-gassing or some suitable refractory material and is mounted by two holders 81 and 83. Holder 81 has a pair of relatively tight swivel joints 85 and 87, while holder 83 has a pair of relatively tight swivel joints 89 and 91. The swivel joints enable the shield 75 to have its two halves positioned so as to adjust the aperture 77. The holders 81 and 83 can be securely fastened to the surface 11 by means of their bases 93 and 95.

By making the metal vapour pass through the aperture 77, the amount of time that any individual substrate is exposed to the vapour is more limited. By varying the size of the aperture 77, the time exposure can be varied to accommodate different thicknesses of deposition on the substrates. The time control of exposure of the substrates to the metal vapour is a most important feature of the shield device. Each time a substrate is tumbled to the top of the pile of substrate a fresh small surface area of the substrate tends to be exposed to metal vapour. In this way the amount of vapour deposited around the entire surface of the substrate is thinner and more uniform.

In addition the shield serves to prevent a great deal of direct heat radiation from the heating element striking the substrates. This, as mentioned earlier, is related to the problem of control over prolonged heat. It has been found that the temperature coefficient, developed in resistors which are metallized on a relatively cold substrate, is constant and controllable; whereas, when the substrates become relatively hot, the temperature coefficient is not controllable and varies in the end product. The shield provides enough buffer action between the heating element and the substrates to keep them relatively cool and therefore enable the production of a resistor having a constant temperature coefficient.

It has been found empirically that when the shield is used, the thin film resistors that are produced enable a helical cut to be made therein and the resultant spiral shaped resistance path has a uniform resistance value along its entire length.

By encapsulating these resistors in epoxy resin they have been found to withstand continuous operation at 175°C.

WHAT WE CLAIM IS:—

1. A process for producing a thin metallic film on a substrate by the technique of subjecting the substrate to the metal vapour under conditions of heat and vacuum, in which process a plurality of said substrates are caused to be tumbled together while being subjected to the metal vapour under said conditons of heat and vacuum, and the proximity of the source of metal vapour to the overall volumetric space occupied by said plurality of substrates while they are being tumbled is variable to enable control of the process.

2. A process according to claim 1, in which said overall volumetric space is generally shielded from said source of metal vapour and said vapour is only permitted to reach said volumetric space via a special access area thereto of predetermineable and variable dimensions.

3. Apparatus for carrying out the process of claim 1, including an evacuable chamber, a hollow drum in said evacuable chamber rotatable about a horizontal axis, said drum having means which upon rotation of the drum cause a plurality of substrates to be tumbled together when positioned therein, a heating element positioned within the chamber and means for closely associating, in operation, said heating element with a metal to be evaporated, and a device by means of which it is possible

to vary the proximity of said heating element (and thereby in operation the source of metal vapour also) to a lowermost internal region of the drum coupled in operation by said plurality of substrates.

4. Apparatus according to claim 3, in which said heating element is in the form of an elongate rod extending within the drum parallel with the axis of rotation of same.

5. Apparatus according to claim 3 or 4, in which a shield is provided and is disposed between the source of metal vapour (and thereby said heating element also) and said lowermost internal region so as to generally shield the latter from receiving the metal vapour, said shield having therein an aperture of variable size to provide a spacial access area through which the vapour can penetrate into said lowermost internal region.

6. Apparatus according to claim 5, in which a device is provided by means of which the proximity of said shield to the source of metal vapour and said lowermost internal region is variable.

7. Apparatus according to claim 3, 4, 5 or 6, in which said drum rests in operation upon rollers fixedly mounted on a pair of spaced-apart shafts in order to be readily removable from and replacable on said rollers, said rollers, in operation, frictionally engaging the outer surface of said drum so that rotation of said rollers causes rotation of the drum.

8. Apparatus according to any of claims 3 to 7, in which, in operation, the metal being vaporized is wound around, or otherwise placed in contact with, said heating element.

9. Apparatus according to any of claims 3 to 8, in which, in operation, the metal being vaporized is contained in a receptacle mounted in close proximity to said heating element.

10. A process according to claim 1 and substantially as described herein.

11. A process according to claim 1 and substantially as described herein with reference to Figure 1, or Figures 1 and 3 of the accompanying drawings.

12. Apparatus substantially as described herein with reference to Figure 1, or this Figure as modified with reference to Figure 2 or Figure 3 of the accompanying drawings.

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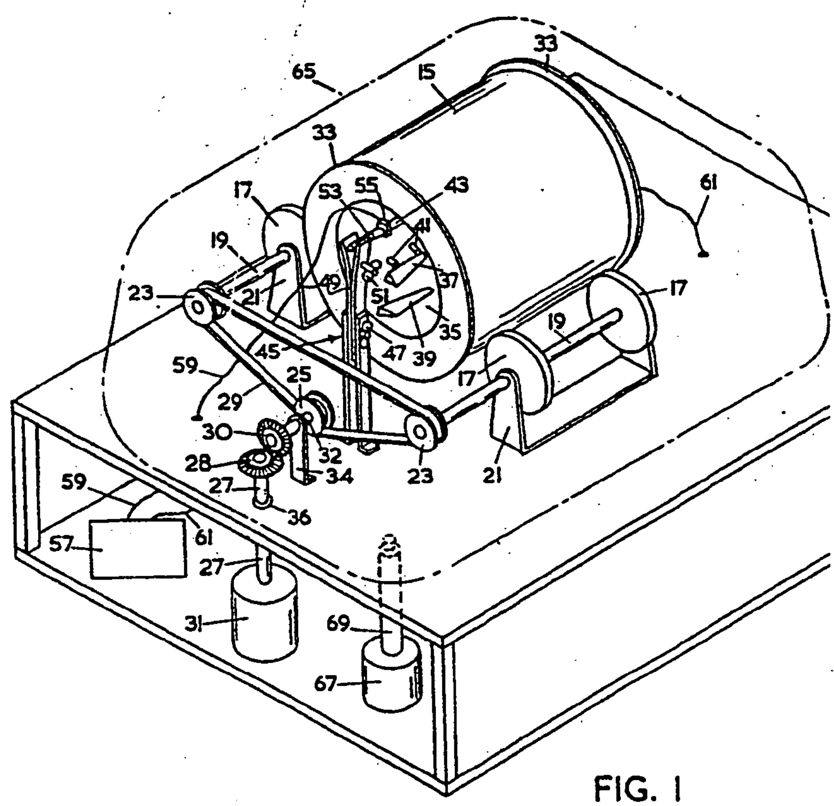
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FIG. 1

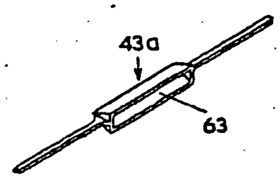
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FIG. 2

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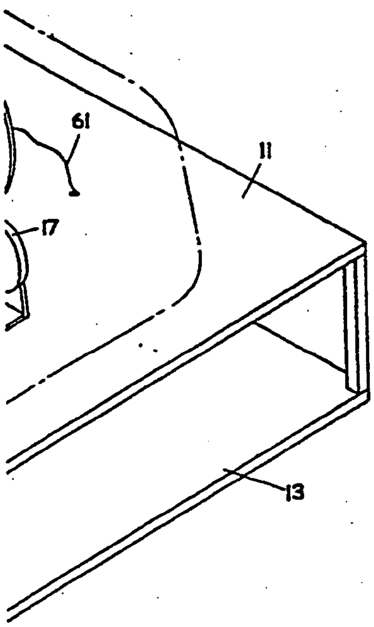

G. 1

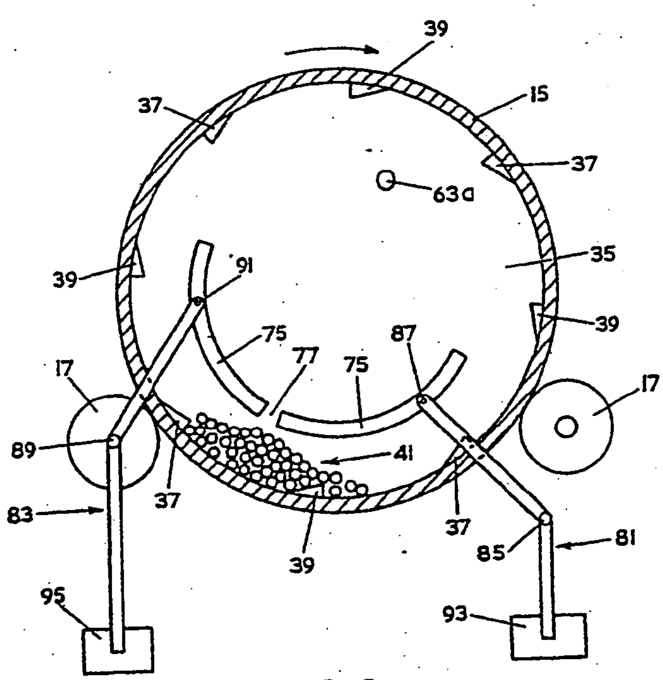

FIG. 3

1074901 COMPLETE SPECIFICATION

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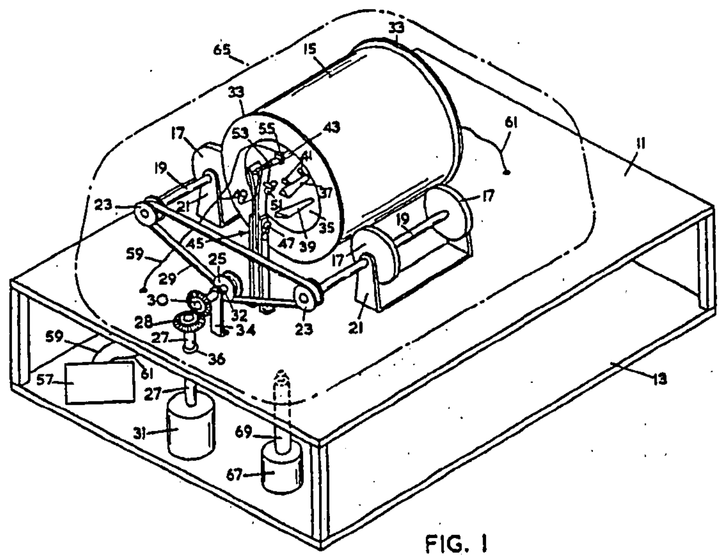

FIG. 1

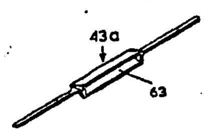

FIG. 2

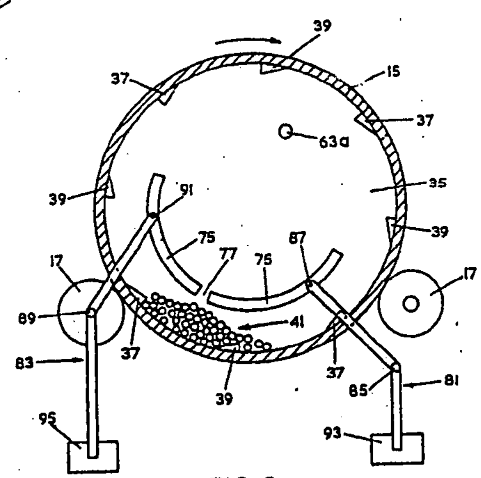

FIG. 3